February 1, 1900.

The LORD LISTER, F.R.C.S., D.C.L., President, in the Chair.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "A Case of Monochromatic Vision." By Sir W. DE W. ABNEY, K.C.B., F.R.S.

II. "Thermal Radiation in Absolute Measure." By Dr. J. T. BOTTOMLEY, F.R.S., and Dr. J. C. BEATTIE.

III. "Electrical Conductivity in Gases traversed by Cathode Rays." By J. C. MCLENNAN. Communicated by Professor J. J. THOMSON, F.R.S.

IV. "Researches on Modern Explosives. Second Communication." By W. MACNAB and E. RISTORI. Communicated by Professor RAMSAY, F.R.S.

V. "On the Influence of the Temperature of Liquid Air on Bacteria." By Dr. ALLAN MACFADYEN. Communicated by LORD LISTER, P.R.S.

"On the Effects of Strain on the Thermo-electric Qualities of Metals. Part II." By MAGNUS MACLEAN, M.A., D.Sc. Communicated by LORD KELVIN, G.C.V.O., F.R.S. Received November 22, 1899,—Read January 25, 1900.

A.—*Thermo-electric difference between free wires and wires previously subjected to longitudinal extension and lateral compression, by drawing them through the holes of a draw-plate* (§§ 1—7).

§ 1. In Part I of this paper, read to the Society on 2nd February, 1899, the object of the experiments was stated to be the determination of the *magnitude* of the thermo-electric effects, obtained from any one metal strained and unstrained. The results then given were obtained from two wires of the same material, one wire being previously drawn through a draw-plate, so as to reduce it in size from No. 18 standard gauge (0·122 cm. diameter) to about No. 24 standard gauge (0·0559 cm. diameter). The arrangement of the experi-

ments to measure the thermo-electric effect is shown diagrammatically in fig. 1. One junction of the wires was kept in a glycerine bath which could be heated by a Bunsen burner. This junction was tied by a fine copper wire to the bulb of a thermometer T. The other ends of the wires were joined to short copper wires, which served as terminals of the low resistance galvanometer used in the experiments. These junctions were wrapped in paraffin paper or cotton wool, which contained the bulb of a thermometer T′ reading half degrees from 0° C. to 25° C. A paper screen S was hanging vertically between the Bunsen burner and the thermometer T′ and the galvanometer, to prevent any heat from the flame reaching the rest of the circuit by radiation. These precautions were taken to make certain that all junctions, except the hot junction, would be at the same temperature. The sensitiveness of the galvanometer was 0·09 mikroampere per division, and as its resistance was 1·5 ohms, the electromotive force at its terminals was 0·135 mikrovolt per scale division.

§ 2. The metals for which results were given in Part I were copper (six specimens), lead (two specimens), platinoid, german silver, reostene, and manganin.*

The present paper gives the results of similar experiments made on specimens of commercial† and pure lead, obtained from Messrs. Johnson and Matthey; and specimens of annealed steel, of aluminium and of nickel.

§ 3. The method of experimenting was to take a piece of the wire and draw it through a few holes of a draw-plate, so as to reduce its cross sectional area to about a quarter. Then two pieces of the wire, one drawn and one undrawn, each 60 cm. long, were joined as in fig. 1. The glycerine bath was very slowly heated by the Bunsen burner. When there was a rise of temperature of 5° C. the Bunsen burner was drawn slightly aside, so as to give as much heat to the glycerine bath as it lost by radiation. When both the thermometer reading and the spot of light on the scale were seen to be steady, the readings were noted. The circuit was then broken and readings taken of the galvanometer zero and the thermometer T′. The circuit was again com-

* Dr. Anderson, Chemical Laboratory, the University, Glasgow, gave me the following analyses for reostene and for manganin:—

Reostene.

Si	0·61	per cent.
Fe	79·95	,,
Ni	16·53	,,
Mn	1·21	,,
Total	98·30	

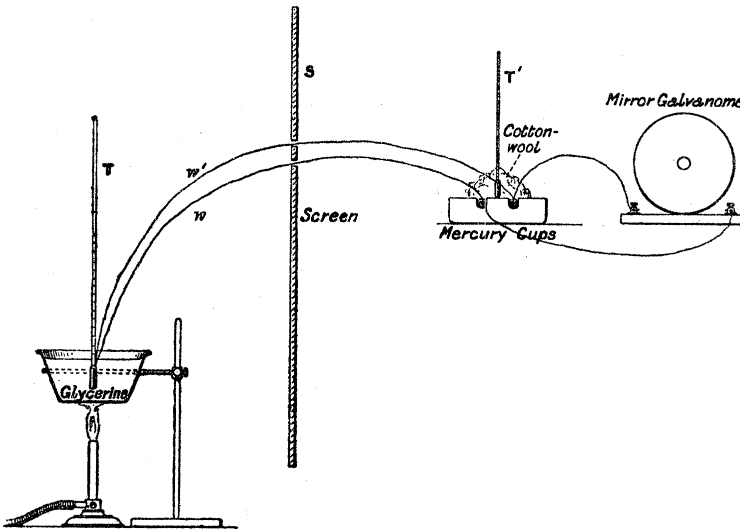
Manganin.

Sn	0·073	per cent.
Fe	0·6	,,
Cu	86·62	,,
Mn	8·031	,,
Ni	3·261	,,
Total	98·585	

† Dr. Anderson analysed the commercial lead and found it contained 99·12 per cent. of lead.

pleted, and readings taken when there was 5° C. further rise of temperature, and so on up to a difference of about 100° C., the greatest difference tried in these experiments. A curve was plotted with

FIG. 1.



differences of temperature between the hot and the cold junction as abscissæ, and currents through the galvanometer as ordinates. The mean current per degree difference of temperature as found from each curve is given in Table I.

Table I.

Conductor.	Condition of conductor. Current from 1 to 2 through the hot-junction.	Current in mikro-ampere per degree up to 100° C.
Annealed steel.........	1. Drawn............ 2. Undrawn..........	0·0567
Aluminium............	1. Drawn............ 2. Undrawn..........	0·0065
Nickel................	1. Drawn............ 2. Undrawn..........	0·213
Lead, commercial	1. Undrawn.......... 2. Drawn............	0·0124
Lead, pure............	1. Undrawn.......... 2. Drawn............	0·0036

§ 4. The steel wire was annealed by coiling it round a large cast-iron ball, which was heated in a bright coal fire for about an hour. After being taken out of the fire, the ball, with the iron wire round it, was

allowed to cool slowly for about an hour and a half in the ashes below the fire. It was previously found that heating the wire to red heat by an electric current and allowing it to cool slowly did not anneal it.

§ 5. The resistances of all the undrawn wires, and the specific gravities of both the undrawn and drawn wires, were carefully determined by the usual laboratory methods. The results obtained are given in Table II.

Table II.

Conductor.	Cross section of undrawn and drawn wires in sq. cm.	Specific gravity of undrawn and drawn wires.	Resistance of the undrawn wires in C.G.S. units at 14° C.	
			Per c.c.	Per cm. long, weighing a gramme.
Steel, annealed	0·007504 0·004141	7·78 7·762	13,900	108,100
Aluminium	0·04594 0·01697	2·8 2·796	3,546	9,931
Nickel	0·01179 0·002475	8·9 8·85	9,430	83,920
Lead, commercial	0·01145 0·00256	11·36 11·36	20,560	233,100
Lead, pure	0·01150 0·00236	11·35 11·357	20,300	230,200

§ 6. By multiplying the current per division given in Table I, by the total resistance in the circuit, calculated from the results in Table II, the thermo-electric difference per degree between drawn and undrawn wires is found. The numbers are given in Table III.

Table III.

Conductor.	Resistance in ohms of 60 cms. of wire.		Total resistance external to galvanometer.	Total resistance in circuit.	Thermo-electric difference in mikro-volt per degree C. difference of temperature.
	Undrawn.	Drawn.			
Steel, annealed	0·1111	0·2015	0·3126	1·813	0·1028
Aluminium	0·0047	0·0125	0·0172	1·517	0·0099
Nickel	0·0480	0·2287	0·2767	1·777	0·3784
Lead, commercial	0·1077	0·4820	0·5897	2·09	0·026
Lead, pure	0·1059	0·5162	0·6221	2·12	0·0076

§ 7. The thermo-electric difference between glass hard tempered steel, annealed steel, and unannealed steel, was found by similar experiments to be :—

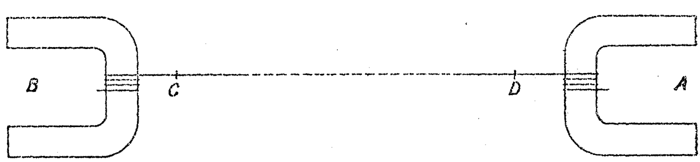
1. Glass hard steel 2. Unannealed steel	} 7·5 mikrovolts per degree C.
1. Unannealed steel 2. Annealed steel...	} 0·18 ,, ,,
1. Glass hard steel 2. Annealed steel...	} 7·67 ,, ,,

The direction of the current through the hot junction was in every case from hard steel to soft steel.

B.—*Thermo-electric difference between free wires and wires previously permanently elongated by longitudinal stresses* (§§ 8—10).

§ 8. Attempts were now made to determine the thermo-electric difference between free wires and wires previously permanently elongated by a longitudinal stress. It was found difficult to elongate the hard wires permanently to any appreciable extent before they broke. Several methods for stretching the wires were tried, and the method finally adopted, was to take two pieces of stout copper rod, bent into the shapes shown at A and B in fig. 2, and to wind the wire to be

FIG. 2.



stretched several times round A and B. The end A was clamped in a fixed vice and the end B fixed in the clamp of a screw arrangement. By turning the screw the wire was stretched tight. Two ink marks were then put on the wire at C and D 60 cm. apart. The screw was very slowly turned, and the distance between C and D measured until the necessary elongation was produced or until the wire broke. The wire generally broke where it lay tangentially to either rod A or B.

§ 9. The greatest percentage permanent elongation that could by this method be got in hard drawn copper, manganin, nickel, and German silver, was 0·7, 0·5, 0·7, and 0·5 respectively. The thermo-electric difference between the stretched and the unstretched wires was then determined, as described in § 3, and the results are given in Table IV.

§ 10. It will be noticed that the current is from unstretched to stretched, through the hot junction for three specimens of copper, and from stretched to unstretched through the hot junction for other three specimens. The probable explanation of these results is suggested in §§ 13, 14, 15.

Table IV.

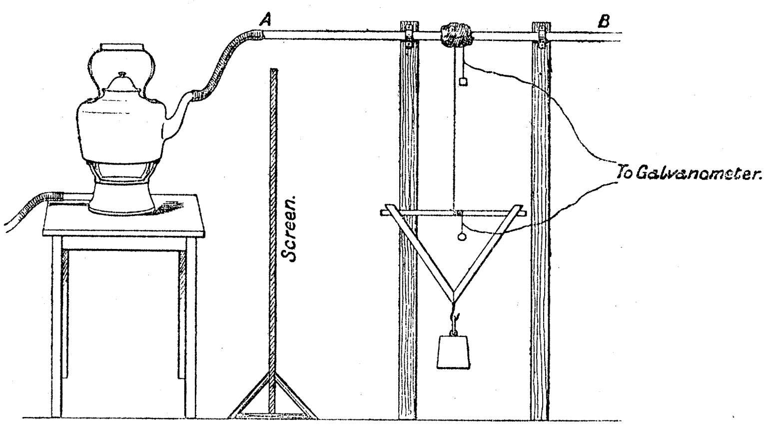
Conductor.	Condition of conductor. Current from 1 to 2 through the hot junction.	Percentage permanent elongation.	Current in mikroampere per degree up to 100° C.	Total resistance in circuit in ohms.	Thermo-electric difference in mikrovolt per degree centigrade difference of temperature.
Messrs. Johnson and Matthey:—					
(*a*) Copper, electrotype	1 stretched 2 unstretched	1·0	0·0021	1·517	0·0032
(*b*) Copper, for alloy	1 stretched 2 unstretched	1·0	0·003	1·519	0·0046
(*c*) Copper, commercial	1 stretched 2 unstretched	1·5	0·0051	1·548	0·0079
Messrs. Glover:—					
(*a*) Copper, hard	1 unstretched 2 stretched	0·7	0·0018	1·519	0·0027
(*b*) Copper, soft	1 unstretched 2 stretched	1·5	0·005	1·531	0·0077
Copper, laboratory	1 unstretched 2 stretched	1·5	0·0024	1·518	0·0036
”	1 unstretched 2 stretched	20·0	0·0174	1·52	0·0264
Reostene	1 unstretched 2 stretched	2·0	0·009	2·312	0·0208
Platinoid	1 stretched 2 unstretched	1·0	0·047	1·937	0·0910
German silver ..	1 stretched 2 unstretched	0·5	0·056	1·835	0·1027
Manganin......	1 stretched 2 unstretched	0·5	0·036	1·924	0·0693
Aluminium	1 stretched 2 unstretched	1·0	0·0135	1·51	0·0204
Nickel	1 unstretched 2 stretched	0·7	0·084	1·596	0·1341

C.—*Thermo-electric difference between free wires and wires under stress, producing* (1) *temporary elongation,* (2) *permanent elongation* (§§ 11—18).

§ 11. The arrangements shown diagrammatically in fig. 3 were now made to determine the thermo-electric difference between free wires and wires while (*a*) under stress, stretching them within their limits of elasticity, and (*b*) under stress, stretching them beyond their limits of elas-

ticity. AB is a brass tube through which steam from a kettle is allowed to pass. The wire under test is wound round this brass tube three times, and then round a small brass tube in the triangular frame below, and then to one of the terminals of the galvanometer. The wire is thus quite continuous, from one terminal of the galvanometer to the other terminal. Some cotton wool is loosely packed at the hot junction of the wire to ensure that the temperature of the wire is at steam temperature. The weight of the triangular frame (two sides wood and

Fig. 3.



one side brass tube) with its hook for hanging weights on was 220 grammes. This is the smallest weight used for each wire, every one of which was about No. 30 S.W.G. (diameter, 0·0315 cm.). The object of the small brass tube in the triangular frame was to keep the temperature of the cold junction at any determined temperature by allowing water or other fluid to flow through it. In all the experiments hitherto made, the temperature of the cold junction was taken as the temperature of the air at the time of each observation.

§ 12. The experiments were performed as follows :—The wire was put into the circuit, as shown in fig. 3. After steam was allowed to pass through the tube for some time, the galvanometer reading and the air temperature were taken. The circuit was then broken, and the metallic zero of the galvanometer was noted. The circuit was made, and a weight was added on to the hook of the triangular frame. Three readings of the galvanometer were now taken : (1) with the weight on, (2) with the weight off, and (3) with the circuit broken. A heavier weight was hung on, and other three readings taken, and so on to the heaviest weight used in the experiments.

§ 13. The readings of the galvanometer were in the same direction

for all the wires tried with weights on and off, except for soft copper and iron. The greatest permanent elongation produced in any of the hard copper wires experimented on was 0·17 per cent., and for this permanent elongation the reading on the galvanometer was in the same direction for weights off and on, though always greater for the latter.

§ 14. For the soft copper wire (Table IX below) the readings were in the same direction for weights on and off, up to a permanent elongation of 1 per cent. After a permanent elongation of 4·72 per cent., the current with weight on was 0·00103 mikroampere per degree from *stretched* to *unstretched* through the hot junction, while with the weight off, the current was 0·00075 mikroampere per degree from *unstretched* to *stretched* through the hot junction.

For iron wire the current was in the same direction for weights on and off, up to a permanent elongation of 0·35 per cent.; but after a permanent elongation of 3·41 per cent. the current with weight on was 0·00461 mikroampere per degree from *unstretched* to *stretched* through the hot junction, and with weight off, 0·0069 mikroampere per degree from *stretched* to *unstretched* through the hot junction.

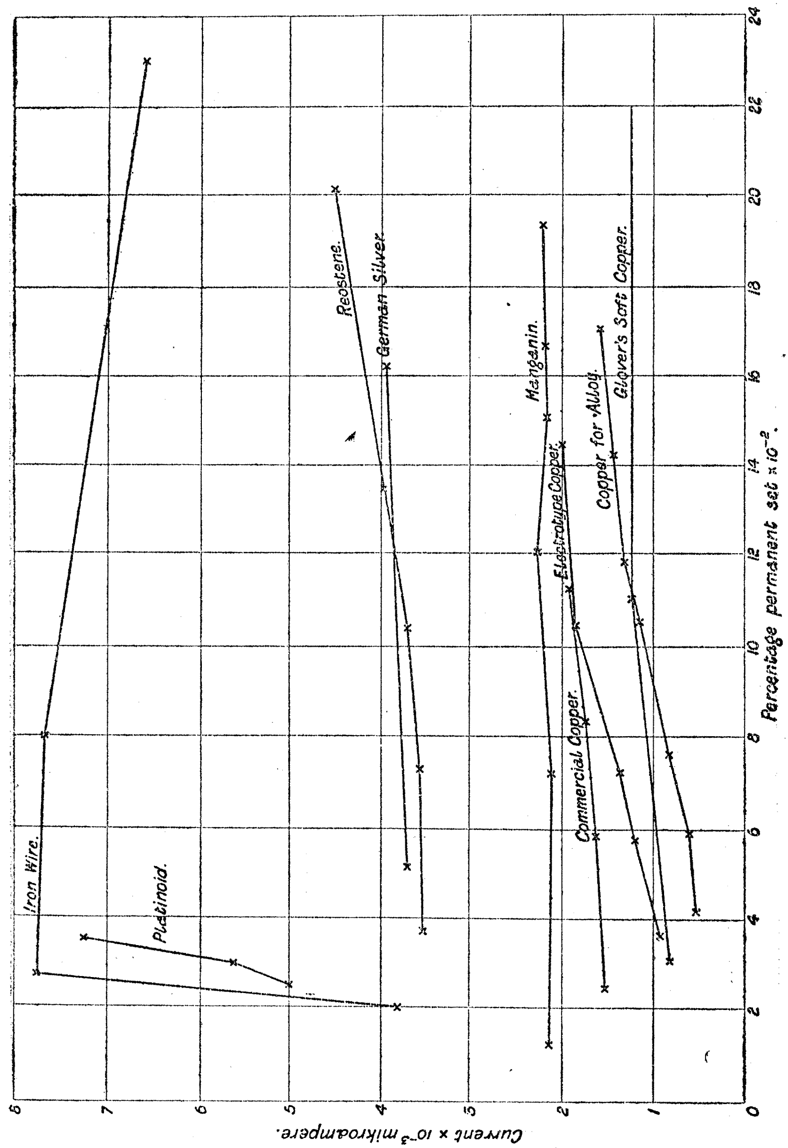
§ 15. In 'Mathematical and Physical Papers,' vol. 2, p. 270, § 109, Kelvin says:—"I have thus arrived at the remarkable conclusion that when a permanent elongation is left after the withdrawal of a longitudinal force which has been applied to an iron or copper wire, the residual thermo-electric effect is the reverse of the thermo-electric effect which is induced by the force, and which subsists as long as the force acts."

It seems (1) that for small longitudinal strain in copper or in iron the direction of the current through the hot junction is the same, whether the force which produced the permanent strain is on or off, (2) that as the permanent elongation is increased by increased longitudinal forces, a stage is reached which gives zero current when the forces are removed, and (3) that for greater longitudinal forces and permanent elongations the direction of the current is opposite, with the pulling forces off and on. It seems, in fact, that the permanent elongation must exceed a definite limit, to produce reverse thermo-electric effects with the longitudinal force on and removed. I hope to further investigate this point and to report the results to the Society.

§ 16. The galvanometer used for the investigation of these temporary and permanent strains was one of the Kelvin recorder pattern, namely, a movable coil between the poles of a strong permanent magnet of circular form. The coil had 81 turns and a resistance 14·94 ohms at 17°·5 C. Its constant was determined in the usual way, and found to be 0·029 mikroampere per division of the scale.

§ 17. To find the stress-strain diagram, experiments were performed on a specimen of each wire, in the following manner. Two pieces of the wire were passed through two small holes in a metal plate, and

soldered at the back of the plate. This plate was fixed to a horizontal support at a convenient height. One of the wires had a half millimetre



scale near its lower end, and a weight hanging on it to keep the wire straight. The other wire had a scale pan and a pointer in the manner generally used in laboratories for finding the Young's modulus of

materials. By putting weights into the scale pan, and taking them out, and noting the readings of the pointer on the scale, the temporary and permanent elongation in the wire for different weights were found. The numbers are given in the second and third columns of Tables V to XIV. The currents in the fourth columns are calculated from the deflections of the galvanometer when the stated weights are on the wire, and the thermo-electric differences in the fifth column are found by multiplying the currents in the fourth column by the total resistance in the circuit in each case.

§ 18. The numbers in the tables are plotted in curves with percentage permanent elongation as abscissæ, and thermo-electric differences as ordinates. The thermo-electric difference between free platinoid and strained platinoid, rises rapidly with the permanent elongation of the strained wire. For manganin and lead, both commercial and pure, it is very nearly constant up to a permanent elongation of $\frac{1}{5}$ per cent.

Mr. Alexander Wood, Thomson Experimental Scholar in the Physical Laboratory, The University, Glasgow, has rendered valuable help in the experimental work and in the calculations.

Table V.—Electrotype Copper.

Current from Stretched to Unstretched.

Temperature difference = 87° C. Total resistance in circuit = 15·56 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	0·06	..	0·00020	0·00311
500	0·1	..	0·000267	0·00415
750	0·137	..	0·000567	0·00882
1000	0·18	0·036	0·000934	0·01452
1250	0·21	0·057	0·001200	0·01867
1500	0·264	0·072	0·00137	0·02127
1750	0·318	0·104	0·001866	0·02905
2000	0·348	0·144	0·002	0·03113

Table VI.—Commercial Copper Wire.

Current from Stretched to Unstretched.

Temperature difference = 88° C. Total resistance in circuit = 16·66 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	0·05	..	0·00119	0·02
500	0·1	..	0·00142	0·0236
750	0·14	..	0·00138	0·0231
1000	0·19	..	0·00148	0·0247
1250	0·23	0·024	0·00152	0·0253
1500	0·28	0·058	0·00161	0·0269
1750	0·32	0·083	0·00175	0·0291
2000	0·37	0·112	0·00191	0·0318

Table VII.—Copper for Alloy.

Current from Stretched to Unstretched.

Temperature difference = 87° C. Total resistance in circuit = 15·62 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	0·08	..	0·000333	0·00521
500	0·145	0·041	0·000533	0·00833
750	0·176	0·059	0·000600	0·00937
1000	0·215	0·076	0·000833	0·01302
1250	0·256	0·105	0·001167	0·01823
1500	0·285	0·118	0·001324	0·02031
1750	0·340	0·142	0·001433	0·02239
2000	0·402	0·170	0·001600	0·02500

Table VIII.—Glover's Hard Copper.

Current from Stretched to Unstretched.

Temperature difference = 86°·5 C. Total resistance in circuit = 15·59 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	..	..	0·000335	0·005226
500	0·006	..	0·000469	0·007316
750	0·014	..	0·001106	0·01725
1000	0·019	0·006	0·001241	0·01934
1250	0·0285	0·0135	0·001375	0·02143

Table IX.—Glover's Soft Copper.

Current from Stretched to Unstretched.

Temperature difference = 87° C. Total resistance in circuit = 15·56 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
300	..	..	0·00020	0·003113
500	0·14	0·03	0·00083	0·01296
750	0·28	0·105	0·00123	0·01919
1000	1·18	1·00	0·00143	0·02225
1200	4·84	4·72	0·00103	0·01608

Table X.—Reostene Wire.

Current from Unstretched to Stretched.

Temperature difference = 86°·5 C. Total resistance in circuit = 43·39 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	0·037	..	0·002682	0·1163
500	0·085	..	0·003521	0·1528
750	0·152	0·037	0·003521	0·1528
1000	0·220	0·073	0·003588	0·1557
1250	0·257	0·104	0·003721	0·1614
1500	0·318	0·134	0·003957	0·1717
1750	0·417	0·201	0·004526	0·1963

Table XI.—Platinoid Wire.

Current from Stretched to Unstretched.

Temperature difference = 86° C. Total resistance in circuit = 29·89 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	0·035	..	0·003541	0·1058
500	0·071	..	0·003979	0·1190
750	0·101	..	0·004451	0·1330
1000	0·130	0·025	0·005125	0·1532
1250	0·16	0·03	0·005631	0·1683
1500	0·19	0·035	0·007285	0·2177

Table XII.—German Silver Wire.

Current from Stretched to Unstretched.

Temperature difference = 86° C. Total resistance in circuit = 26·85 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	..	..	0·002529	0·0679
500	0·08	..	0·002360	0·0634
750	0·105	..	0·002474	0·0661
1000	0·13	..	0·003020	0·0813
1250	0·18	0·051	0·003710	0·0996
1500	0·35	0·162	0·003946	0·1059
1750	0·80	0·588	0·004552	0·1222

Table XIII.—Manganin Wire.

Current from Stretched to Unstretched.

Temperature difference = 86°. Total resistance in circuit = 30 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	..	..	0·001888	0·05665
500	0·145	0·012	0·002124	0·06372
750	0·260	0·072	0·002090	0·06272
1000	0·327	0·120	0·002259	0·06778
1250	0·382	0·151	0·002158	0·06474
1500	0·427	0·166	0·002158	0·06474
1750	0·484	0·193	0·002192	0·06575

Table XIV.—Iron Wire.

Current from Unstretched to Stretched.

Temperature difference = 85°. Total resistance in circuit = 19·20 ohms.

Total weight in grammes.	Percentage temporary elongation.	Percentage permanent elongation.	Current in mikroampere per degree with weight on.	Thermo-electric difference in mikrovolt per degree.
250	..	..	0·0000727	0·000912
500	..	..	0·000131	0·006216
750	0·023	..	0·000131	0·006216
1000	0·03	0·02	0·003813	0·07192
1250	0·06	0·027	0·007816	0·09485
1500	0·19	0·08	0·007736	0·09430
1750	0·39	0·23	0·006602	0·08696
2000	..	3·41	0·00461	0·07576

FIG. 3.